

The Utility of System Dynamics Analysis For Managing Lake Sustainability

NH Lakes Management Advisory Committee
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New Hampshire DES
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Presentation Outline

- Define SDA
- Explain utility in understanding and managing lake carrying capacity
- Summarize value added for making decisions to optimize strategies



System Dynamics Analysis (SDA)

- Innovative approach to evaluate complex problems where factors affecting output are interconnected and change with time
- Methodology that addresses the complex interactions that may lead to unintended consequences and counter-intuitive behavior, simultaneously managing continuous and discontinuous relationships
- Capable of evaluating how systems will behave as a result of change, be it due to decided actions or uncontrolled events.



Challenge – Justification for SDA

- Need to optimize environmental risk management strategies
- Strategy must properly plan and sequence activities to be:
 - Cost and time effective
 - Protective of natural resources
 - Satisfactory to users and non-users of lake



Challenge – Justification for SDA

- 1) **Optimize** (not maximize) the user's lake experience!
- 2) Uses of lake(s) surfaces should be regulated to maintain compatibility among users without degrading lake resources!!!

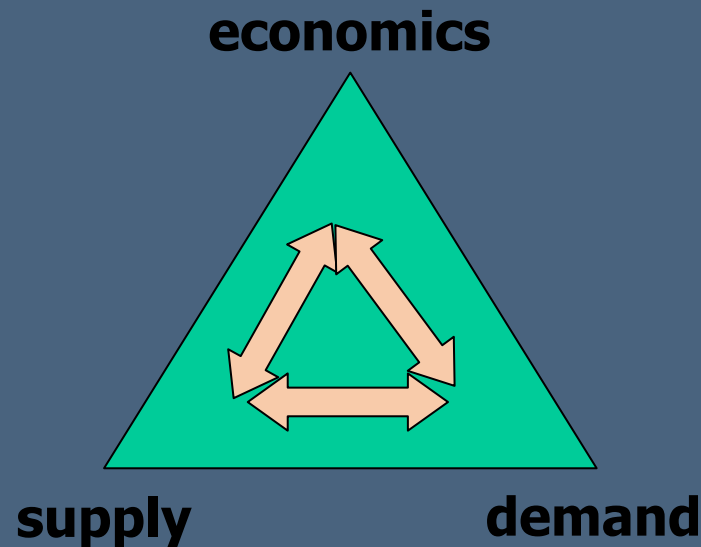


What Are Systems?

- Systems are networks of positive and negative feedbacks
 - Everything is connected to everything else
 - You can't "just do one thing"
 - Unintended consequences and counter-intuitive behavior
- Systems are dynamic because feedbacks interact
 - Nonlinear feedback dynamics
 - Positive feedback: Self-reinforcing, i.e., amplify trends in place
 - Balancing feedback: Self-correcting, i.e., oppose change
 - Causal tracing maps system behavior
- Feedback captures learning, changing future behavior



Simple Yet Complex System of Cause and Effect



What SDA Offers

- Single platform for decision-making
 - Common basis for analysis and choice
 - Integrated consequences
 - Unintended consequences
- Helps decision makers make complicated decisions
 - Multiple options, in series or together
 - Affordability
 - Resource sustainability
 - Capital improvement
- Provides basis for consistent risk communication



Level of Effort Required

**ADAPTABLE TO SCALE OF INTEREST
AND REQUESTED LEVEL OF EFFORT**



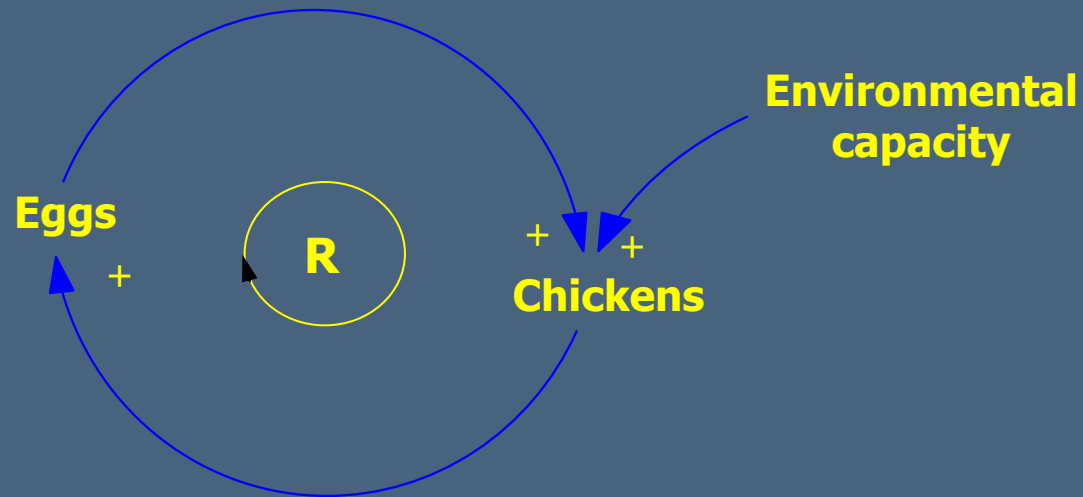
Justification to Use SDA

- Provide insight into a problem
- Develop innovative solutions
- Optimize strategies

CLIENTS INVEST IN SDA WHEN THEY WANT TO BETTER UNDERSTAND AND ACHIEVE THE BEST POSSIBLE RETURN ON THEIR INVESTMENT OR PROTECTION OF ASSETS



Chickens and Egg Example



This is a REINFORCING feedback loop

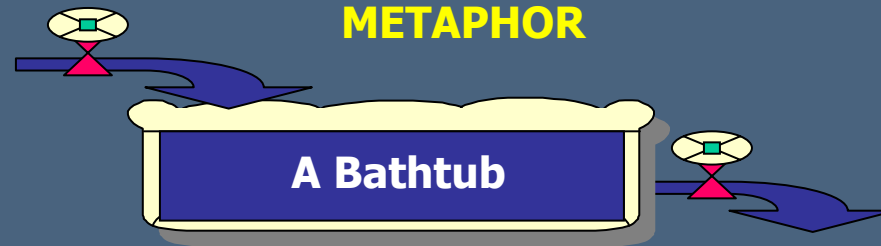


SDA Approach

- Functional relationships
 - Constants
 - Equations
 - Tabular input
 - Graphical interpretations of a relationship
- Definitions of each functional relationship are based on
 - Field characterization data if available
 - Otherwise it is based on hypothetical data that is consistent with those presented in the literature
- Model development and analyses proceed iteratively, refining the model with increasing knowledge of the system
- Sensitivity analyses for the communication and defense of choices to stakeholders



Building Blocks for Analysis: Stock & Flow



STOCK & FLOW DIAGRAM



DIFFERENTIAL EQUATION

$$d(\text{Stock})/dt = \text{Net Change in Stock} = \text{Inflow}(t) - \text{Outflow}(t)$$

From Sterman, 2001



Stock and Flow Formulation

- Mass balance
- Take derivatives with time
- Continuity, chain rule, and rearranging
- Constraints, e.g., equilibrium
- Solve for flows, i.e., fluxes



SDA for Lake Capacity Management

- Aquatic ecosystems are complex systems, with networks of positive and negative feedback loops
- Each management decision may directly an/or indirectly affect several parameters, comprehensively driving, for better or worse, the ecological integrity and sustainability of the lake for its intended use
- SDA needed to understand and predict consequences of management options to optimize outcomes



Multiple Complexities of Carrying Capacity

- Ecological System
- Sociological Phenomenon
- Human and Watershed Development

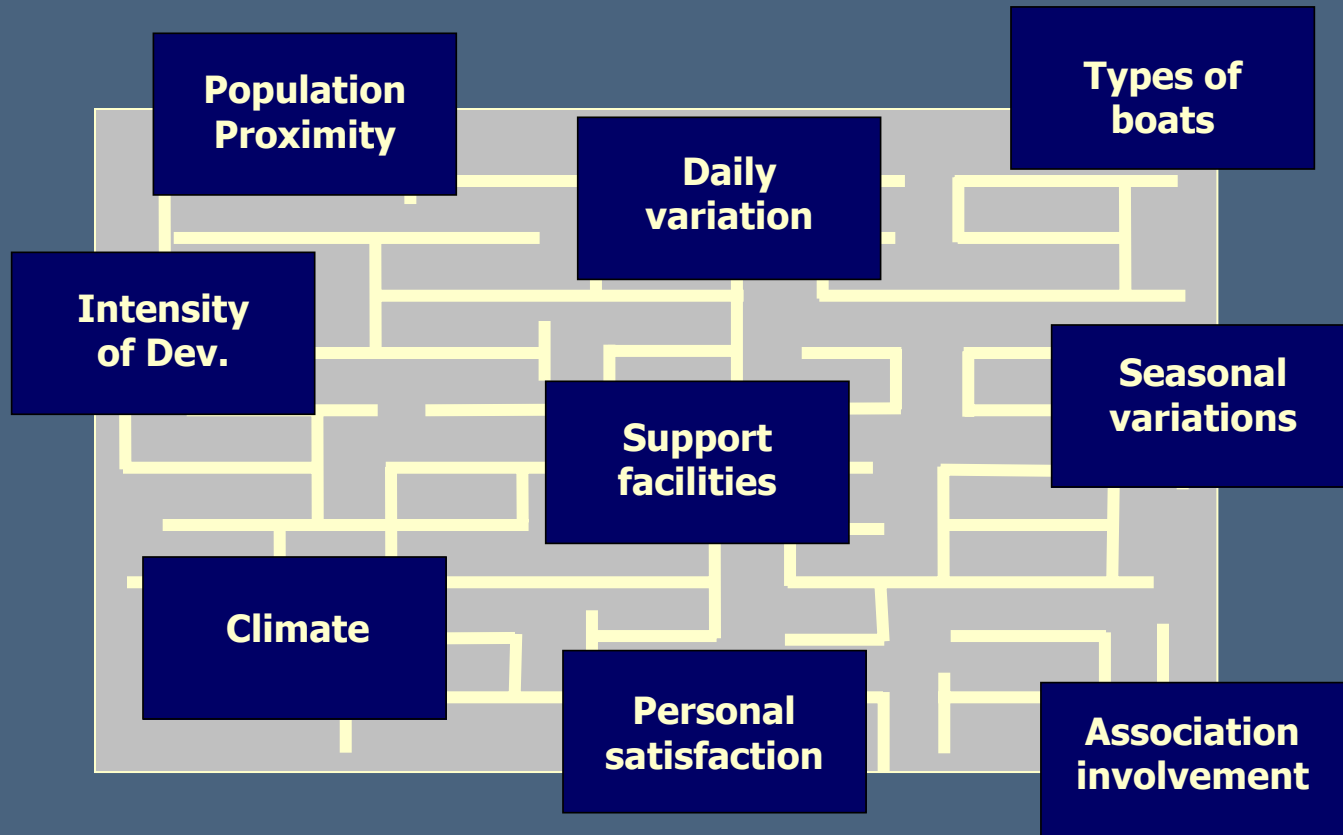


Carrying Capacity Management Tools

- **Spatial** - limit use(s) to certain lakes or portions of lakes
- **Time** - limit use(s) to time of day and/or day of the week
- **Activity** - limit use to certain lakes and/or portion of lakes (zones)
- **Horsepower limits**



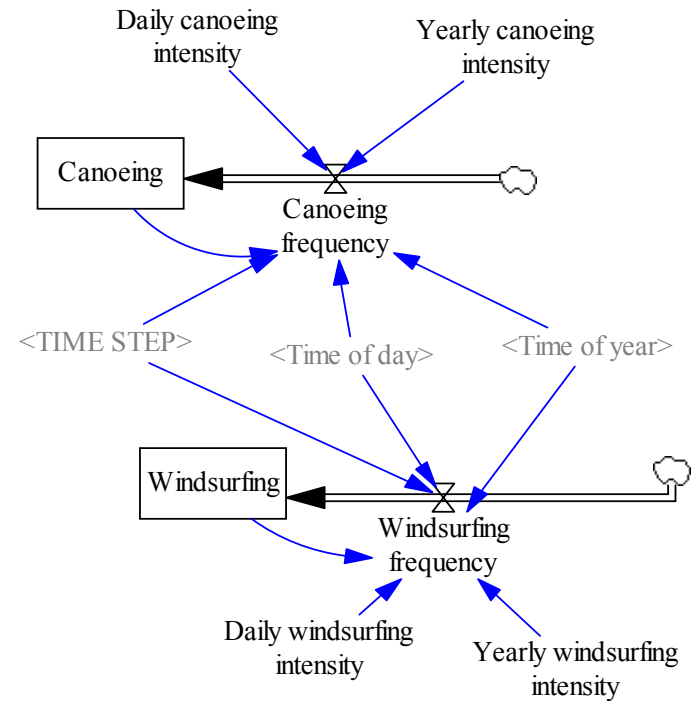
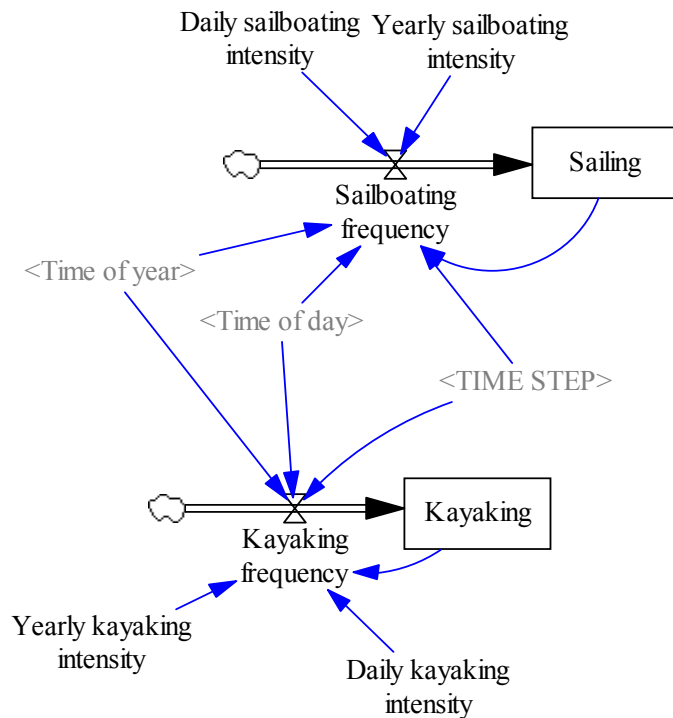
Multiple Factors/Decisions/Events Challenges Intuition



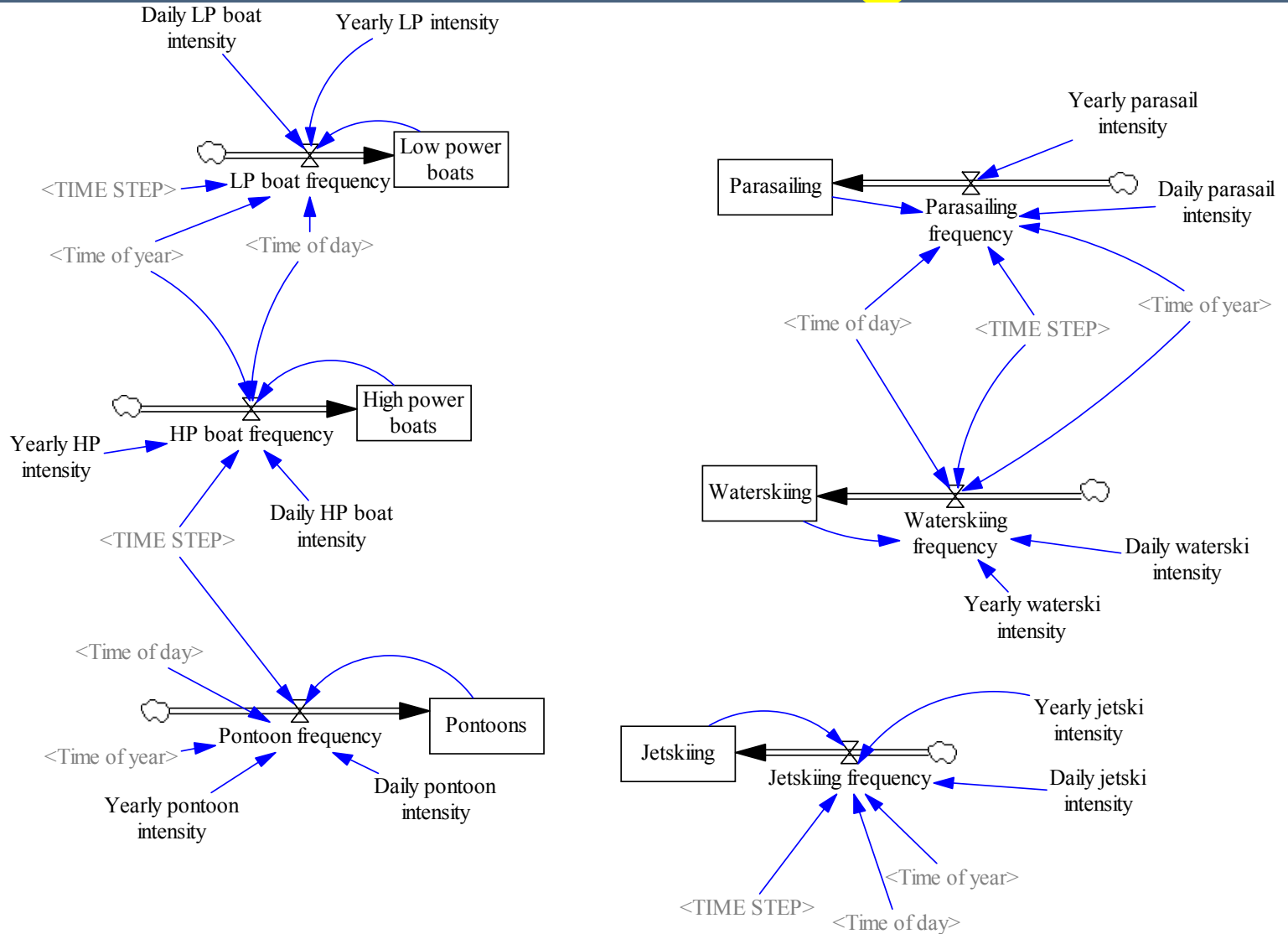
Dynamic modeling provides for consistent decision process



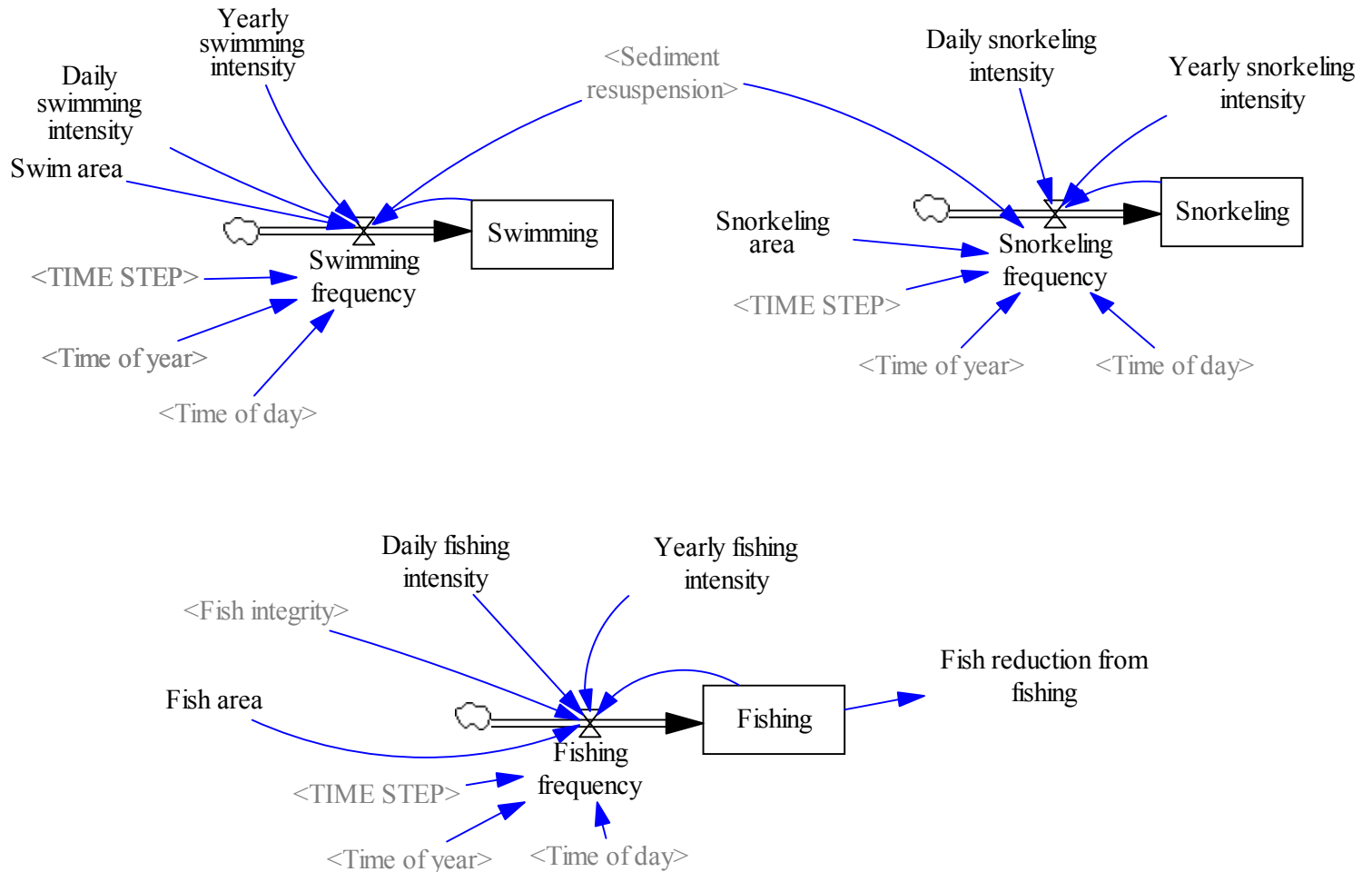
Stock and Flow – Non-Powered Boating



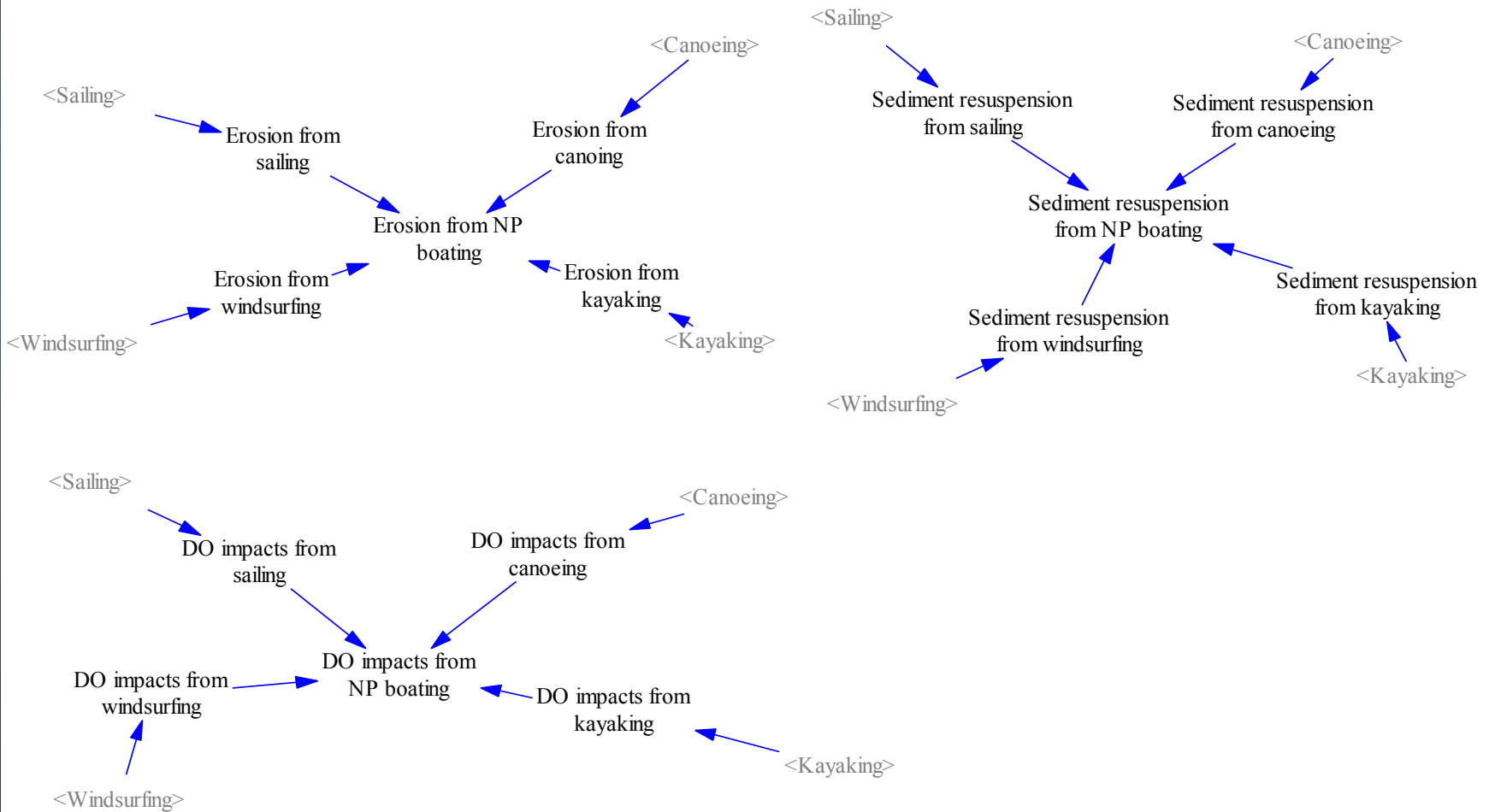
Stock and Flow – Powered Boating



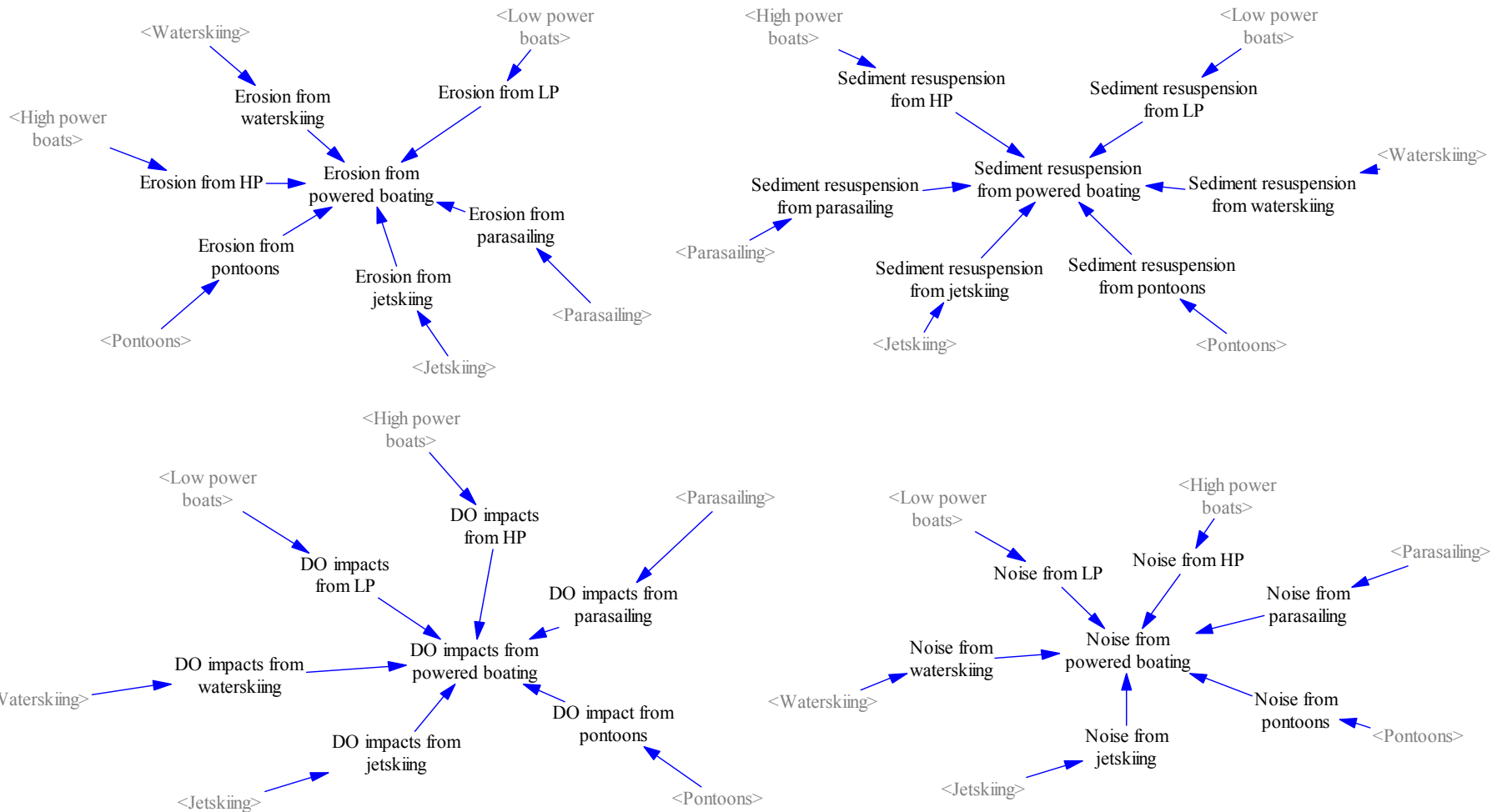
Stock and Flow – Individuals' Activities



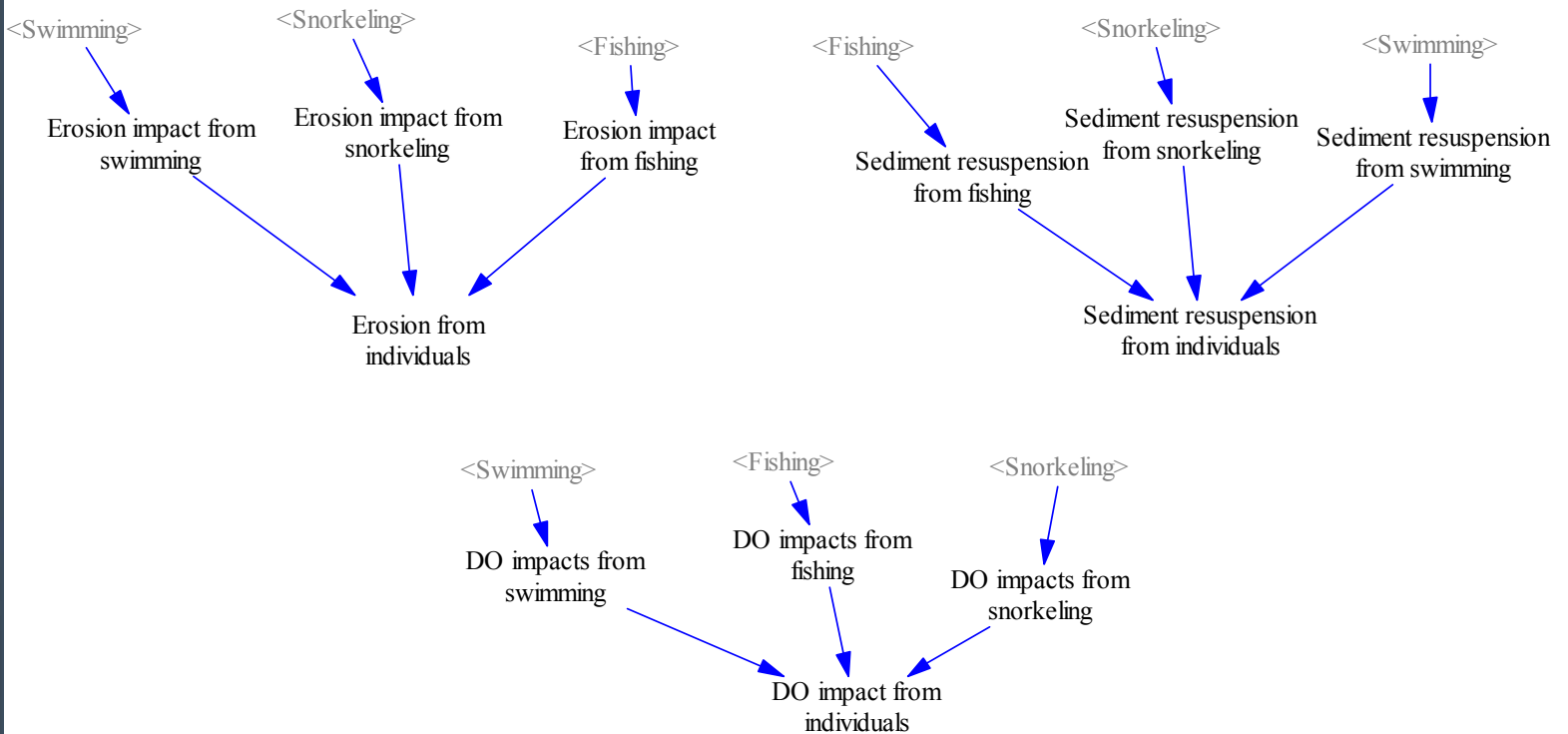
Stock and Flow – Non-Powered Boat Impacts



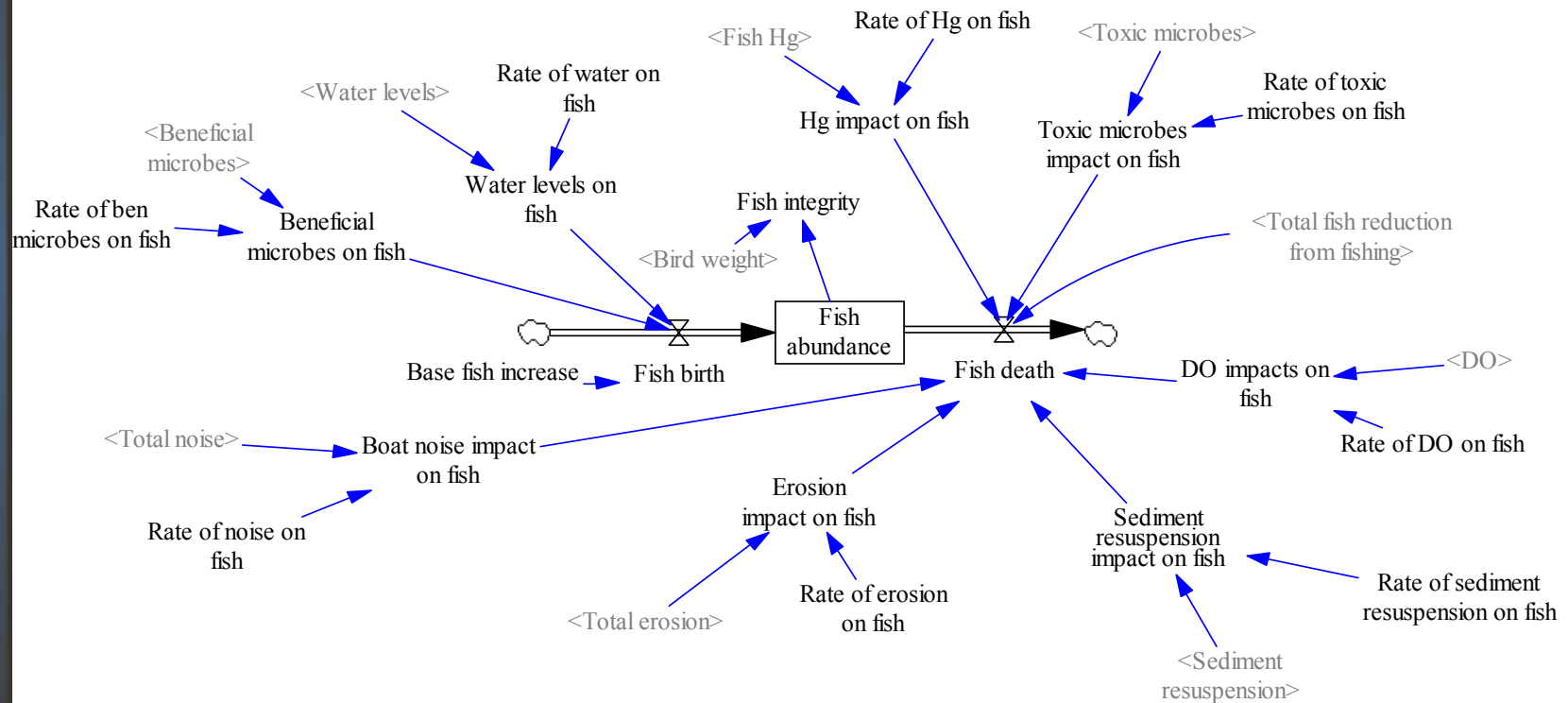
Stock and Flow – Powered Boat Impacts



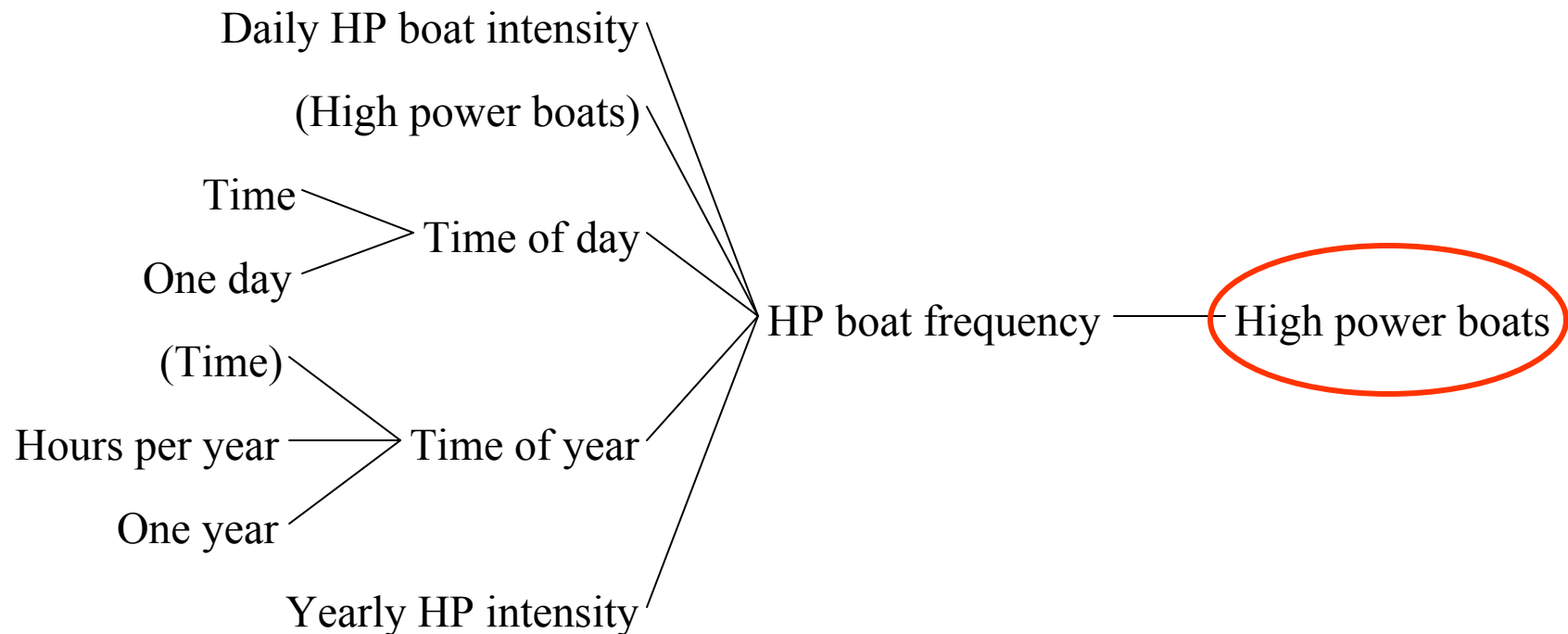
Stock and Flow – Individuals' Impacts



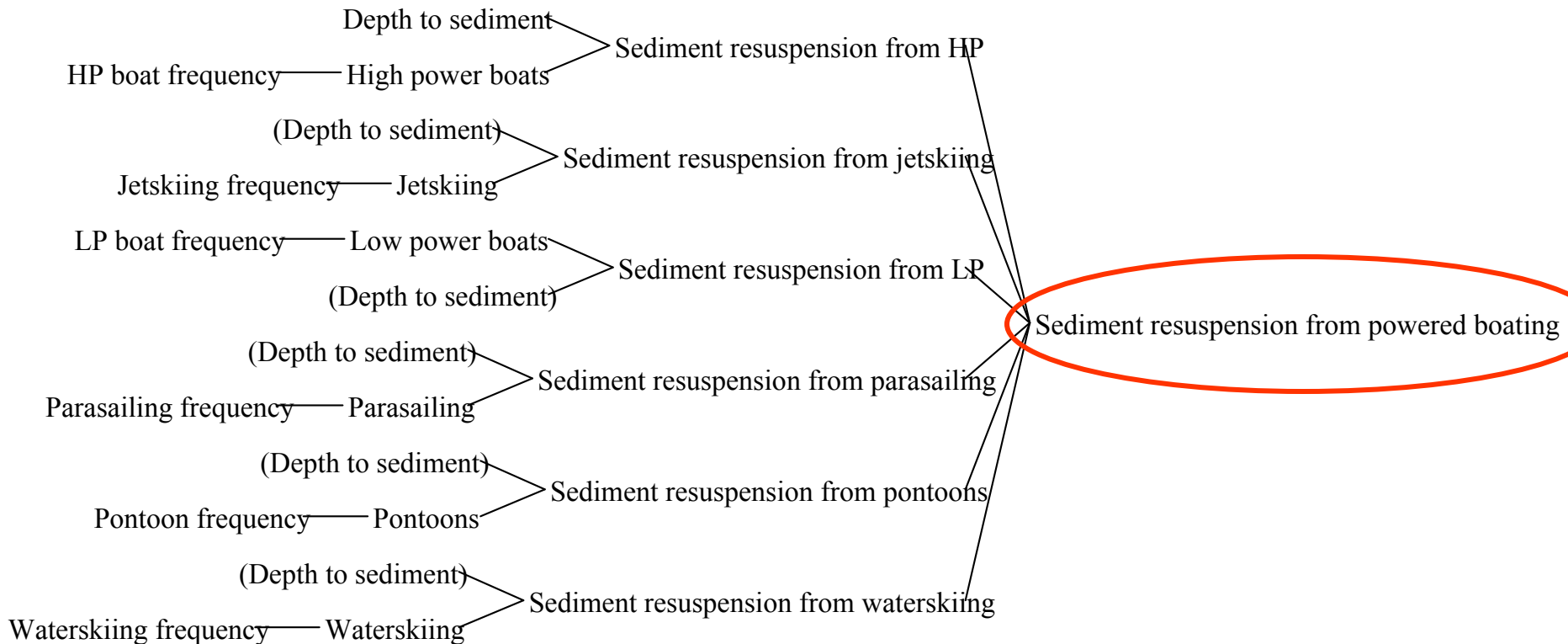
Stock and Flow - Fish Integrity



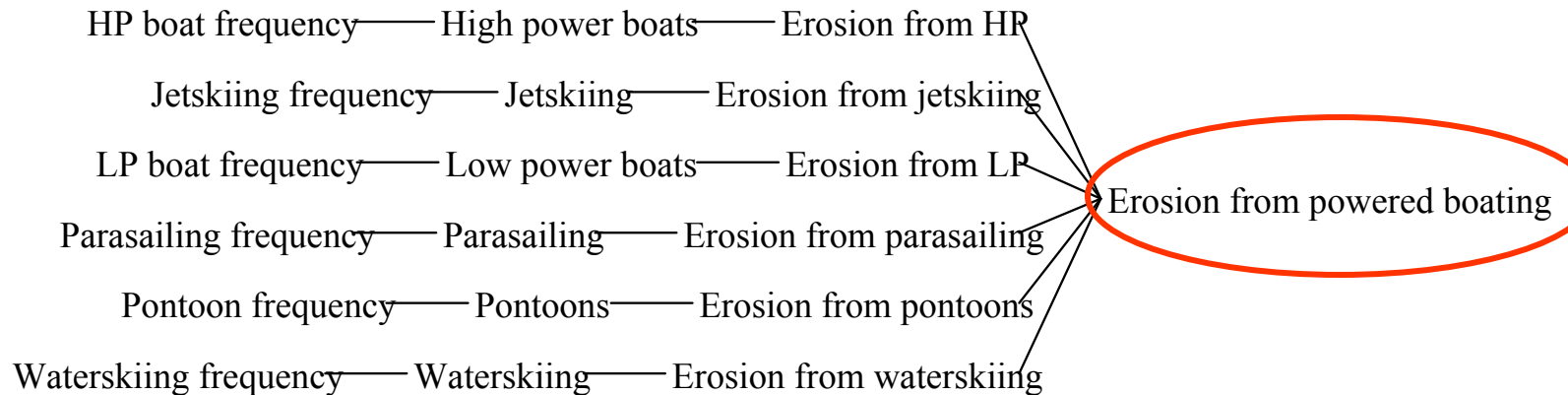
Causes Tree – High Powered Boats

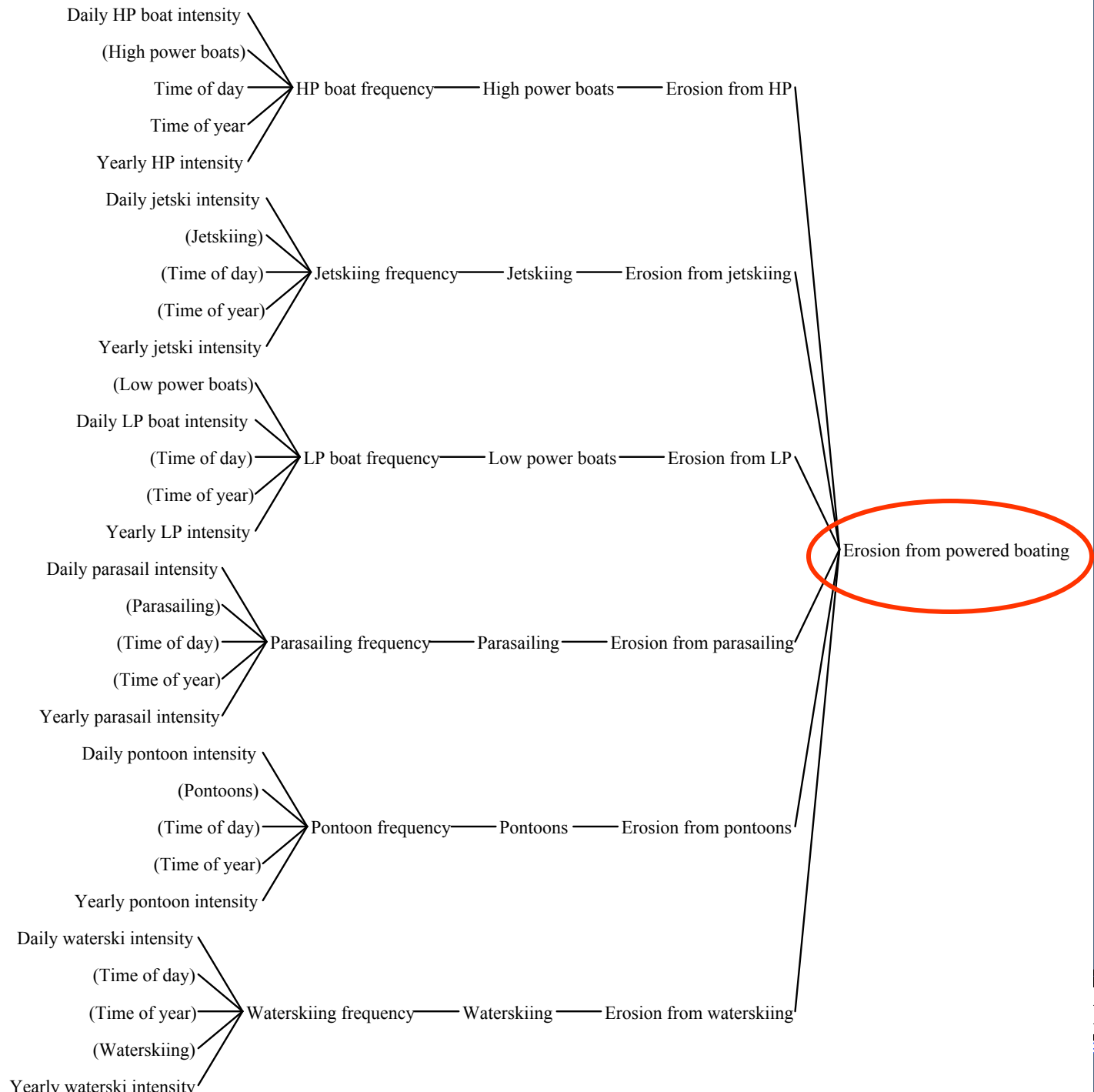


Sediment Resuspension from Powered Boats



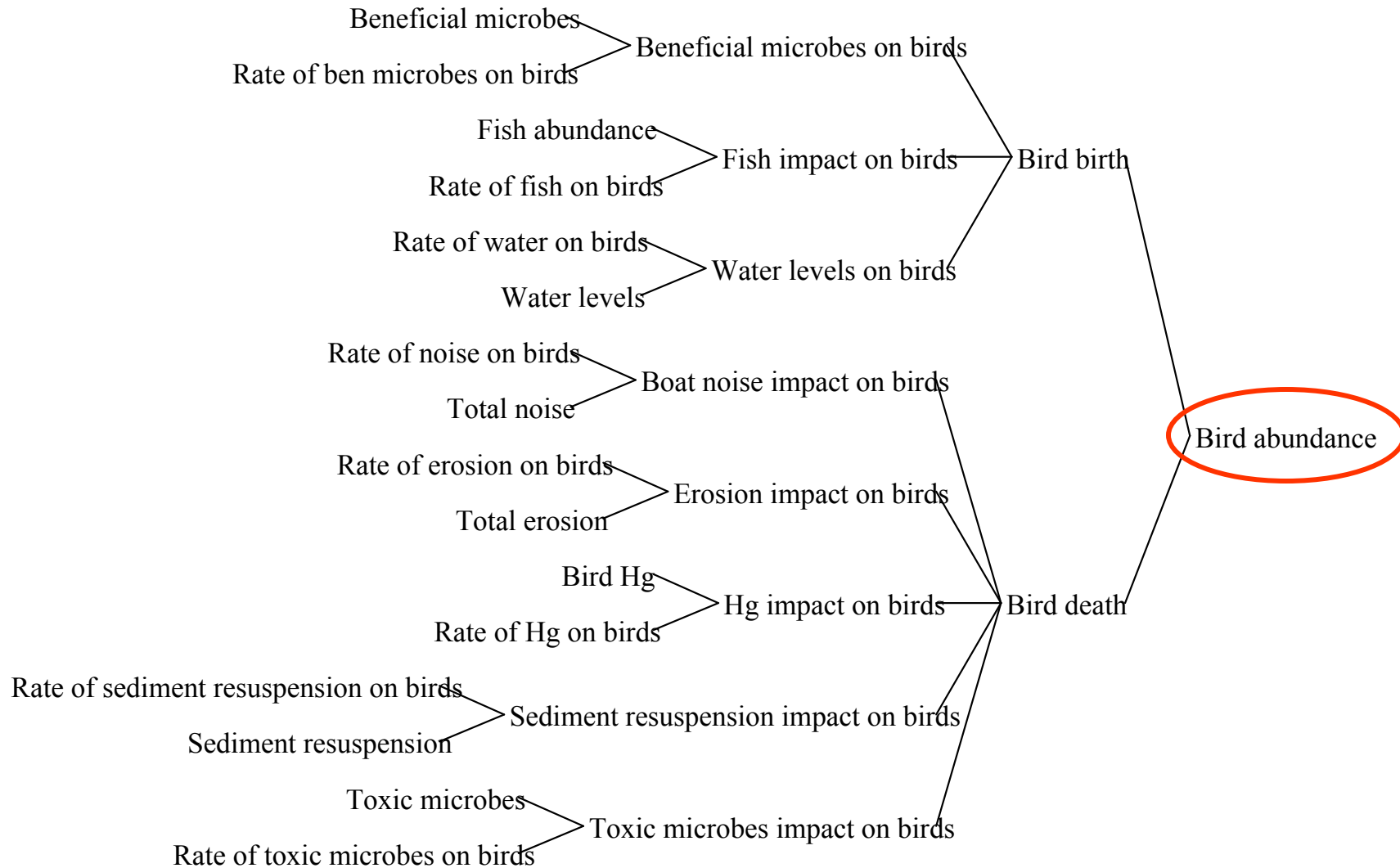
Erosion from Powered Boats





Biological Indicators

Bird Abundance



Justification to Use SDA

- Exceeds DECISION RISK ANALYSIS (DRA)
 - Feedback
 - Details
 - Active analysis
- Logical and visual
- State of the art
- Dynamic
- Any metric
- Advanced math not needed ...but applied
- Scenarios and long term impact

